INSTRUCTION BOOK

for

BALLANTINE MODEL 440
SELBY* MICROPOTENTIOMETER

*MR. MYRON C. SELBY OF NATIONAL BUREAU OF STANDARDS,
BOULDER, COLORADO

Manufactured by

BALLANTINE LABORATORIES, INC.

BOONTON, NEW JERSEY

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WARRANTY

Ballantine warrants that each Model 440 will be suitable for calibration by the National Bureau of Standards.

Each Ballantine Laboratories, Inc. instrument, or part thereof, is warranted to be free from defects in material and workmanship. Ballantine Laboratories, Inc. obligation under this warranty is limited to repairing or replacing any instrument or part thereof, except vacuum tubes and thermocouples, which shall within one year after shipment to the original purchaser prove upon Ballantine Laboratories, Inc. examination to have become defective.

INSTRUCTION BOOK
FOR
BALLANTINE MODEL 440 SELBY MICROPOTENTIOMETER

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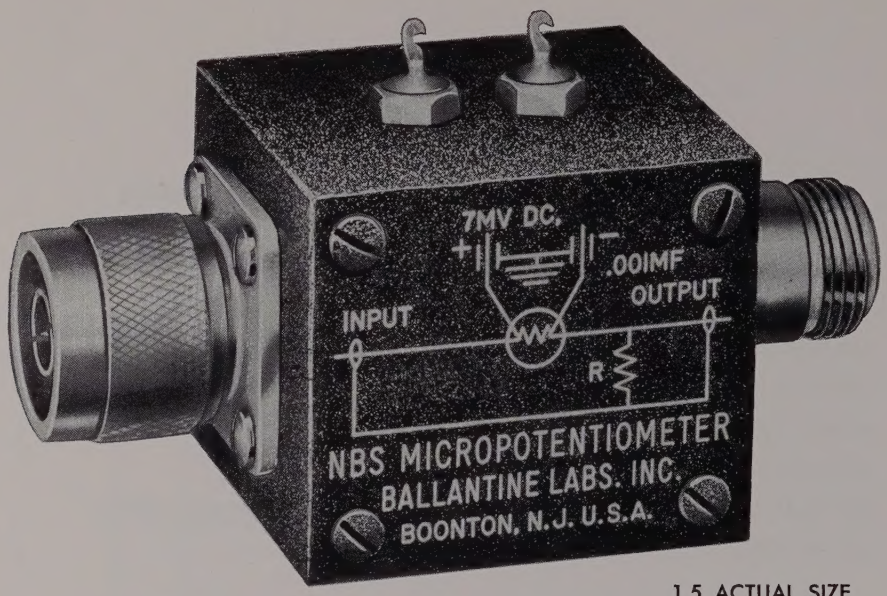
ADDITIONAL INFORMATION

A paper entitled "Techniques and Errors in High Frequency Voltage Calibration" by Dr. Endel Uiga and Wallace F. White is attached to and made a part of this instruction book.



1.5 ACTUAL SIZE

Figure 1 — Ballantine Model 440 Selby Micropotentiometer

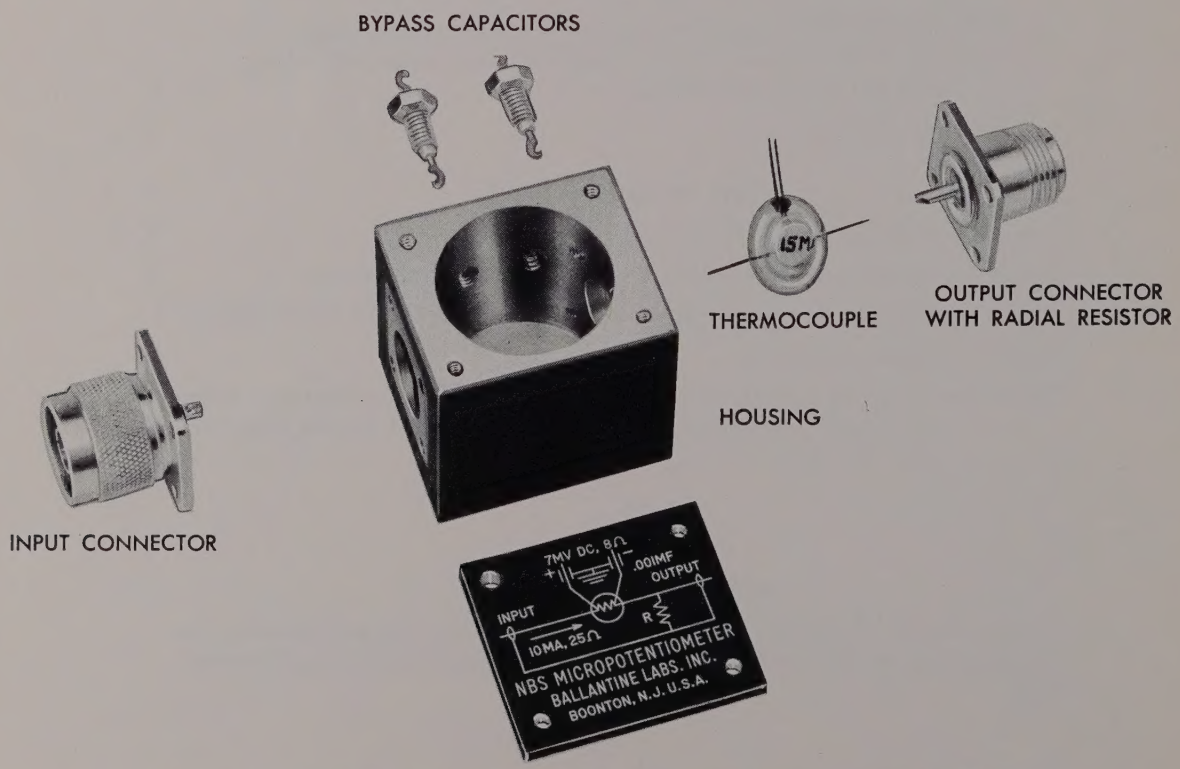


Figure 2 — Ballantine Model 440 Selby Micropotentiometer, Exploded View

1. SPECIFICATIONS

Radial Resistors

Available in nominal values from .010 to 22 ohms with ±20% tolerance. Each resistor is supplied soldered in Type N female coaxial connector.

Housings

Normally supplied with either a 5, 10 or 15 mA UHF-type thermocouple. Higher thermocouple ratings available on request.

Voltage Range

17 microvolts to 0.4 volt dependent on combination of radial resistor and thermocouple selected. Each combination will have a nominal output voltage equal to the product of resistance and rated thermocouple current, and can be varied from 1/3 to 1-1/3 of this nominal output.

Outputs greater than 0.4 volt can be obtained by using higher thermocouple ratings. For example, a 50 mA thermocouple with a 22 ohm resistor will produce outputs from 0.37 to 1.4 volts.

Frequency

DC to 900 megacycles.

Accuracy

As of December, 1961, the accuracies quoted on calibration certificates from the NBS Calibration Center, Boulder, Colorado, are 2% at 5 Mc, 3% 100 Mc to 400 Mc, and 5% 500 Mc to 900 Mc. Users of Micropotentiometers should check with NBS from time to time regarding any change in these figures.

Calibration and Certification

Model 440 Micropotentiometers may be calibrated and certified by the National Bureau of Standards Calibration Center, Boulder, Colorado, at frequencies up to 900 Mc. Because of the heavy work load at NBS, Ballantine has agreed to provide calibration and certification for each Radial Resistor/Thermocouple combination at the following frequencies: 5 Mc, 100 Mc, 300 Mc, 400 Mc, and 500 Mc.

Ballantine calibration and certification accuracies will be based on the accuracies of *special standards supplied for this service by NBS*. It is expected that the additional uncertainty introduced by the Ballantine calibration will not exceed 1% up to 500 Mc.

Calibration from 500 Mc to 900 Mc by Ballantine may be supplied sometime during 1962 but during the early part of 1962 such calibrations should be obtained from NBS, Boulder, Colorado. Please check with Ballantine during 1962 regarding this service.

2. PURPOSE

The Ballantine Model 440 Micropotentiometer is designed to provide a precisely determined voltage at its output terminal when dc to 900 megacycles current is fed into the input terminal. The input current flows through a UHF-type thermocouple to a radial resistor of known constant value. The voltage developed across the resistor becomes the standard which can be used to calibrate electronic voltmeters, oscilloscopes, signal generators and other devices.

The Model 440 is manufactured by Ballantine Laboratories based on designs by Mr. Myron C. Selby of the National Bureau of Standards, Boulder, Colorado. It is licensed under patents of the U. S. Government.

3. DESCRIPTION

Figure 1 shows the complete Model 440 Micropotentiometer assembly. Figure 2 is an exploded view showing the housing with a Type N male coaxial input connector, a UHF-type insulated thermocouple for monitoring the input current, screwdriver, and plugged into any other housing carrying a thermocouple of a different rating. If, for example, we use a 0.02 ohm radial resistor and a 5 milliampere thermocouple it is possible to produce a standard voltage output of

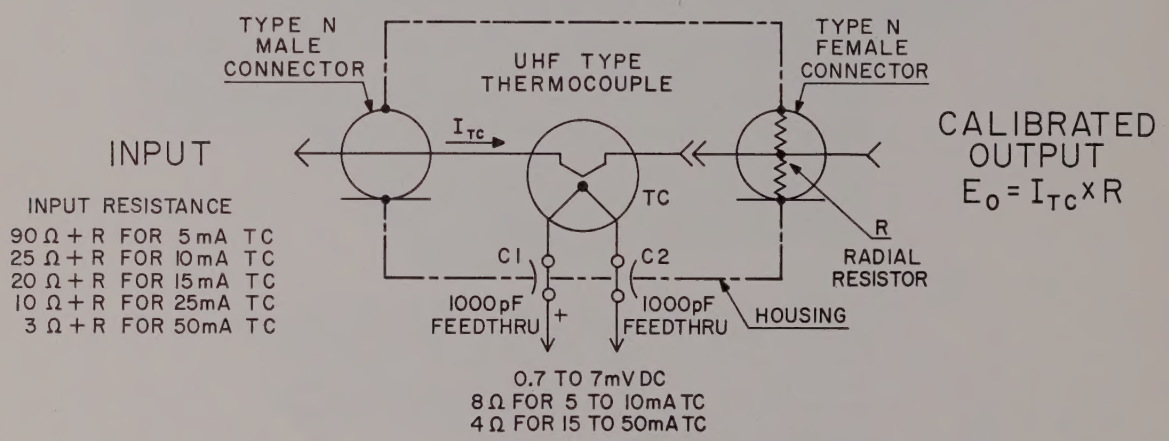


Figure 3 — Ballantine Model 440 Selby Micropotentiometer, Schematic Circuit Diagram

two feed-thru capacitors to provide leads to a dc microammeter, and a special radial resistor which is built into a Type N female coaxial output connector. Figure 3 is a schematic circuit diagram of the instrument.

Construction of the radial resistor is most important, and special techniques must be used to make one whose resistance remains nearly constant from dc to beyond 500 Mc. If the current provided by an external signal generator is maintained constant, as indicated by a constant thermocouple output read on an external dc microammeter, the voltage drop across the radial resistor can be used as a precision low impedance source of voltage whose output remains constant from dc to beyond 500 Mc.

The nominal output voltage of a Model 440 is given by the product of the heater current rating of the thermocouple and the resistance of the radial resistor. This voltage can be varied from one-third to one and one-third of full rated output by varying the thermocouple current over a four-to-one range. To provide additional voltage ranges, any radial resistor can be easily removed with the aid of a 100 microvolts for 5 milliamperes current, and 40 microvolts for 2 milliamperes current. Higher resistor values of 22 ohms, and thermocouples rated to 15 milliamperes may be used to produce voltages to approximately 0.44 volt. It is possible to use a 50 mA thermocouple with a 22 ohm radial resistor to obtain 1.4 volts provided the signal generator feeding the micropotentiometer is capable of supplying this amount of current.

Additional laboratory standard devices made by Ballantine are the Model 390 A-T Voltmeter designed to measure voltages from 1 volt to 300 volts in the frequency range from 10 Mc to 1000 Mc, and the Model 393 High Frequency Transfer Voltmeter designed to measure voltages from 1 volt to 50 volts in the frequency range of 25 cps to 30 Mc. These are also based on NBS designs. A laboratory equipped with Model 440 Micropotentiometers for low voltages, Model 390 for high voltages, and Model 393 for high voltages at higher accuracy up to 30 Mc, will have a wide voltage range as well as a wide frequency range in its laboratory basic ac voltage standards.

4. OPERATION AND APPLICATIONS

The Model 440 Micropotentiometer is ready for use as received. It is necessary only to connect the input to a source capable of delivering the required current over the frequency range desired, and to attach a suitable dc microammeter to the thermocouple output. The Micropotentiometer is then ready to serve as a precision source of low-level, high-frequency voltage.

CAUTION . . . When making connections to the output connector avoid excessive strains on the center conductor to prevent damaging the radial resistor.

The rf output voltage of the Micropotentiometer, at any frequency, is given by the product of the thermocouple current, whose magnitude is indicated by the dc couple output, and the calibrated impedance of the radial resistor. Normally a Micropotentiometer will reproduce the same output voltages for long periods of time. However, the value of the radial resistor may change due to aging effects and the relationship of thermocouple heater current to dc couple output may change as the result of momentary overloads. The Micropotentiometer output, however, can always be standardized at either dc or low-frequency ac where accurate milliammeters and voltmeters are readily available. Within its specified range the Micropotentiometer will then reproduce this voltage at high frequencies with an accuracy as shown on the Test Report. Standardization should be carried out at the ambient temperature at which the Micropotentiometer will be operated, or an additional error due to the temperature coefficient of the thermocouple will be introduced. In all cases, allow the thermocouple at least 10 minutes of operation at the desired current level to produce complete temperature stabilization.

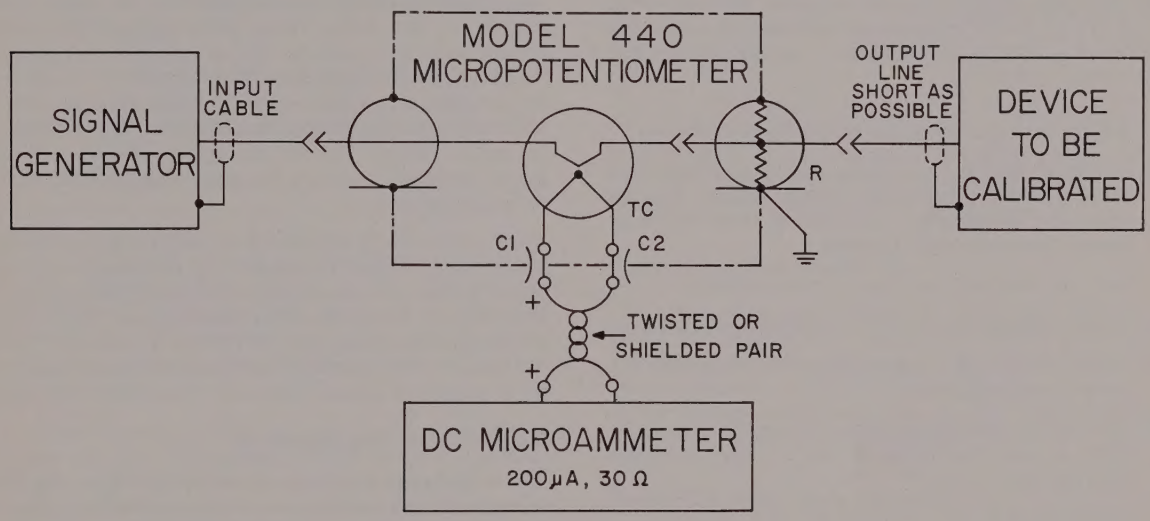


Figure 4 — Typical Test Setup

CAUTION . . . Continuous current overloads of greater than 50%, or momentary overloads of more than 100%, can ruin or seriously alter the thermocouple characteristics.

Figure 4 shows a typical test setup using a Model 440 Micropotentiometer. One application of the Model 440 Micropotentiometer is in the calibration of sensitive high-frequency voltmeters. The Model 440 may be used to check

the frequency response of voltmeters, relative to some reference frequency, or by calibrating the Micropotentiometer output against auxiliary standards at dc or low-frequency ac, it may be used as an absolute voltage standard. The Model 440 Micropotentiometer may also be used, in conjunction with an auxiliary transfer device, to calibrate the appropriate output levels of signal generators over a wide frequency range. Because the radial resistance is of a low value and securely soldered into a Type N coaxial connector, Micropotentiometers are useful devices whenever a stiff, well-shielded, high-frequency voltage source is required.

FOR USE AS A RELATIVE VOLTAGE STANDARD, 0-900 Mc (to check frequency response of voltmeters, oscilloscopes, etc. For example, to calibrate the frequency response of a vacuum tube voltmeter in terms of an arbitrary reference level.)

1. Adjust the signal generator to a reference frequency.
2. Adjust the level of the signal generator to produce the desired Micropotentiometer output voltage into the voltmeter. **CAUTION . . . Do Not Exceed 150% of Rated Thermocouple Current.**
3. Note the indication on the dc microammeter.
4. Adjust the signal generator to a new desired frequency.
5. Adjust the level of the signal generator to produce the same current as in Step 3.
6. The Micropotentiometer output voltage into the voltmeter is now maintained at the arbitrary reference level selected in Step 2.
7. Repeat Steps 4 - 6 as required for each frequency.

FOR USE AS AN ABSOLUTE VOLTAGE STANDARD, 0-900 Mc (to calibrate voltmeters, oscilloscopes, etc.)

1. Replace the signal generator in Figure 4 with a dc or low-frequency source.
2. Replace the voltmeter to be calibrated with a standard voltmeter (dc or ac, as selected in Step 1) having the correct voltage range and sufficient accuracy to measure the desired Micropotentiometer output voltage.
3. Adjust the level of the input until the standard voltmeter indicates the desired Micropotentiometer output voltage.
4. Note the indication on the dc microammeter.
5. Replace the dc or low-frequency source with a signal generator covering the desired frequency range.
6. Replace the standard voltmeter with the voltmeter to be calibrated.
7. Adjust the level of the signal generator until the dc microammeter indicates the same current as in Step 4.
8. The Micropotentiometer output voltage into the voltmeter is now maintained at the absolute level selected in Step 3.

Device To Be Calibrated (See Figure 4)

Certain precautions are necessary if the device to be calibrated is to respond as desired to the Model 440 output voltage. The input resistance of the device should not load the Micropotentiometer, and the input capacitance should be small to minimize the transmission-line effect discussed below. The capacitance should be measured at the frequencies at which the measurements are to be made, rather than relying on a low-frequency value, because the two will often be considerably different.

In addition, consideration should be given to the effects of ground currents, even if an isolation transformer is being used. Any impedance existing between the input ground terminal of the device being calibrated, and the internal ground point to which the device responds (for example, the ground of the input tube of an amplifier) can serve, in the presence of ground current, to inject in series with the Micropotentiometer output an additional unknown and uncontrolled voltage. Correct grounding practices are absolutely necessary if a high-frequency voltage calibration is to be meaningful.

The purity of the waveform of the input signal is discussed below titled, "Signal Generator". If the device to be calibrated is true rms-responding, there should be no problem regarding the waveform of the source signal. If it is a peak or average-responding type of VTVM, waveform of the input signal is very important for precision measurements. Refer to paragraph "Signal Generator" for further information.

Output Cable (See Figure 4)

The output cable that connects the Model 440 to the device being calibrated should be as short as possible and in the form of a shielded coaxial cable to minimize ground current, pickup, and transmission-line effects.

If a length of coaxial cable is terminated in its characteristic impedance, the voltage along the cable will be constant and equal to the impressed voltage. If the cable is terminated in any impedance other than its characteristic impedance, the voltage along the cable will vary as a function of the terminating impedance, the characteristics and length of the line, and the frequency. Figure 5 shows the relationship of

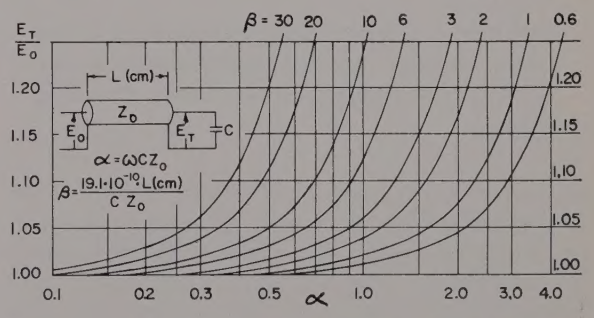


Figure 5 — This family of curves shows the relationship between the voltage at the flange of the output connector of the Model 440 and the voltage existing at distances from this point.

output voltage to impressed voltage for a section of transmission line terminated in a capacitance. For other terminations similar curves can be derived from standard transmission-line equations.

As an example of the transmission-line effect, assume a high-frequency voltmeter to be connected to a Micropotentiometer by means of a coaxial adapter. The total length from the flange of the Micropotentiometer to the output tip of the adapter is 2 inches. The voltmeter is to be calibrated at a frequency of 250 Mc where its input shunt resistance is 1000 ohms and shunt capacitance is 6.4 pF (micro-micro farads). The shunt resistance can be neglected since it is large compared to the capacitive reactance. Using the formulas shown on Figure 5:

$$\alpha = \omega C Z_0 = 2\pi\,(250 \times 10^6)\;(6.4 \times 10^{-12})\;(50) = 0.5$$

$$\beta = \frac{19.1 \times 10^{-10} L(\text{cm})}{C Z_0} = \frac{19.1 \times 10^{-10}\;(2 \times 2.54)}{(6.4 \times 10^{-12})\;(50)} = 30.4$$

Figure 5 then shows that the voltage appearing at the tip of the output UHF connector will be 20% higher than the calibrated output voltage of the Micropotentiometer. If the length of cable can be reduced to a length of approximately 0.4 inches, the error will be reduced to 3%. This example demonstrates the large errors that can occur at high frequencies due to the transmission-line effect, and illustrates the need for extremely short interconnections as the frequency increases.

Short interconnections are also necessary to reduce the effects of ground currents. *Circulating ground currents of various frequencies exist in any system of interconnected electronic equipment connected to a common power line.* If any appreciable impedance exists in the ground connection between the Micropotentiometer and the devices being calibrated, these currents will produce a voltage drop across the impedance which is injected in series with the Micropotentiometer output to the device. At the microvolt and millivolt level such extraneous signals can produce large errors. The ground impedance may be resistive, due to poor electrical connections, or excessive lead length, or inductive due to lead length, or failure to use coaxial cable and connectors.

The effects of ground currents can often be substantially reduced by using an isolation transformer. This transformer may be introduced in the power line of either the generator or the device being calibrated, where it must exhibit small coupling to high-frequency signals.

The output cable from the Model 440 must also be adequately shielded to prevent pickup of high-level signals in the low-level Micropotentiometer output.

DC Microammeter (See Figure 4)

A dc microammeter is required to monitor the rf thermocouple heater current by responding to the dc output of the couple. The absolute accuracy of this indication is of secondary importance. It is important that the microammeter be stable, easily read and reset to a reference value, and of correct sensitivity to indicate near full-scale current for rated thermocouple heater current.

All thermocouples used in the Model 440 have a nominal 7 millivolt open-circuit dc output for rated heater current. The 5 mA and the 10 mA type thermocouples have a dc output resistance of 8 ohms; the 15 mA unit has 4 ohms. For the microammeter to indicate full-scale for rated heater current, the product of full-scale microammeter current times the total dc circuit resistance should equal 7 millivolts. The total circuit resistance is the sum of the couple resistance (either 4 or 8 ohms), the meter resistance, and any added series resistance.

As an example, for a 10 milliampere thermocouple with an 8 ohm couple resistance, we could use a 200 microampere full-scale meter having 10 ohms resistance by adding a series resistance of 17 ohms. Then $200 \times 10^{-6}\;(8 + 10 + 17) = 7 \times 10^{-3}$, as required.

The dc output of the Model 440 is available at the terminals of two high-frequency by-pass capacitors. The connection of the dc microammeter should be made by either a shielded, twisted pair or a coaxial cable to prevent possible pickup of low-frequency fields.

Input Cable (See Figure 4)

The input cable that connects the signal generator to the Model 440 may be of any convenient length. It should be a shielded cable to avoid leakage of the high-level generator output into the low-level Micropotentiometer output circuit. At the Micropotentiometer end, the cable should be terminated in a Type N female connector.

Signal Generator (See Figure 4)

The signal generator used to supply thermocouple heater current to the Model 440 must meet several requirements. Naturally it must be capable of delivering the desired current to the resistance provided by the thermocouple heater, and it must do so over the entire frequency band of interest. In addition, the generator must supply this current with minimum distortion.

The Model 440 is an rms-responding device because it uses a thermocouple to monitor the current that flows thru the radial resistor. If the device which is being calibrated at the output of the Micropotentiometer is also rms-responding, distortion in the waveform of the current supplied by the signal generator will have no effect on the accuracy of the calibration. However, if the device being calibrated is average or peak-responding, distortion in the waveform will cause an error in calibration. The amount of this error is proportional to the magnitude of the harmonics present and their phase relationship to the fundamental.

It may be difficult to measure adequately the distortion in the generator output at high frequencies. Oscilloscopes may be used for a visual indication, and an rf distortion meter may be valuable. The use of additional tuned circuits or coaxial low-pass filters between the generator and Micropotentiometer should also be considered as a means of reducing the error produced by the waveform if such distortion is suspected.

5. GENERAL DISCUSSION OF WAVEFORM vs. ACCURACY OF ELECTRONIC VOLTMETERS

Electronic voltmeters may be classified into three groups according to the way in which they respond to the input signal. In the first group are those instruments that measure the average value of the ac voltage. In most cases, the scale of the indicating meter of these instruments is calibrated to read in terms of the rms value of a sinewave. In the second group are the instruments that respond to the peak value of the ac voltage. All instruments having a diode rectifier at their input are included in this classification. Here again the scale calibration is usually in terms of the rms value of a sinewave. In the third group are the instruments, such as the Ballantine Models 320 and 350, that respond to the actual rms value of the ac signal regardless of its waveform.

If a wave under measurement is a pure sinewave, the indicated rms values of all three groups of instruments will be the same. However, if the wave under measurement has harmonic or unwanted frequencies, the different groups of voltmeters will respond differently. In all cases the average-responding meters will give a much truer indication of the rms of the fundamental alone, or of the rms of the fundamental plus the harmonic, than the peak-responding-type meters. Of course the true rms VTVM will be the most accurate of all when used to measure complex waveform voltages.

The amount of error introduced by a harmonic is a function of both its magnitude and its harmonic phase relationship. The following table compares the errors of two types of voltmeters in the rms indications of waves with various harmonics whose amplitude is 20% of the fundamental and whose phasing is such as to produce maximum error in each case.

The Model 440 Micropotentiometer is used to measure the true rms voltage regardless of the waveform of the input signal. If an average-responding or a peak-responding voltmeter is being calibrated it is essential that a pure sinusoidal signal be fed to the Micropotentiometer because this type of signal is the one on which the calibrations are based. If a true-rms voltmeter is being calibrated the waveform of the signal is no importance.

Form of Wave	*RMS Value of Fundamental*	*RMS Value of Fundamental plus Harmonic*	*Maximum Error in Indicated RMS Compared with RMS of Fundamental*	
			Peak Responding Meter	*Average Responding Meter*
Pure Sine	1.	1.	0	0
Sine Plus 20% 2nd Harmonic	1.	1.02	20%	1.9%
Sine Plus 20% 3rd Harmonic	1.	1.02	20%	6.7%
Sine Plus 20% 4th Harmonic	1.	1.02	20%	1.7%
Sine Plus 20% 5th Harmonic	1.	1.02	20%	4.0%

APPENDIX

VOLTAGE COVERAGE WITH DIFFERENT RADIAL RESISTOR-THERMOCOUPLE COMBINATIONS

The recommended range of voltage coverage for each Radial Resistor-Thermocouple combination is approximately four to one, that is, from approximately 35% above rated thermocouple current to 33% of rated thermocouple current. Thus a Radial Resistor of 0.10 ohms and a Thermocouple rated at 10 milliamperes may be operated between 330 and 1350 microvolts. A tabulation of the microvolt ranges for nominal values of Radial Resistors and for three Thermocouples is given in the table below.

Actual values of Radial Resistors will seldom have the exact nominal values shown in the table. If the Radial Resistor referred to above has 0.12 ohm instead of 0.10, the operating range with a 10 milliampere Thermocouple will be from 396 to 1620 microvolts.

The dc resistance of Radial Resistors will be ±20% of the nominal resistances shown in the table below. Each Radial Resistor is identified by a serial number, and by its accurate dc resistance marked on a metal foil attached to the unit.

See page 2 regarding possible use of thermocouples having higher ratings than shown in the table.

RADIAL RESISTOR (Nominal value in ohms)	MINIMUM - MAXIMUM VOLTAGE (μV)		
	5 mA THERMOCOUPLE	10 mA THERMOCOUPLE	15 mA THERMOCOUPLE
0.010	17 - 67	33 - 135	50 - 200
0.015	25 - 100	50 - 200	75 - 300
0.022	37 - 145	75 - 290	110 - 440
0.033	55 - 220	110 - 440	165 - 660
0.047	80 - 310	160 - 620	240 - 940
0.068	115 - 450	230 - 900	340 - 1,350
0.10	170 - 670	330 - 1,350	500 - 2,000
0.15	250 - 1,000	500 - 2,000	750 - 3,000
0.22	370 - 1,450	750 - 2,900	1,100 - 4,400
0.33	550 - 2,200	1,100 - 4,400	1,650 - 6,600
0.47	800 - 3,100	1,600 - 6,200	2,400 - 9,400
0.68	1,150 - 4,500	2,300 - 9,070	3,400 - 13,500
1.0	1,700 - 6,700	3,300 - 13,500	5,000 - 20,000
1.5	2,500 - 10,000	5,000 - 20,000	7,500 - 30,000
2.2	3,700 - 14,500	7,500 - 29,000	11,000 - 44,000
3.3	5,500 - 22,000	11,000 - 44,000	16,500 - 68,000
4.7	8,000 - 31,000	16,000 - 62,000	24,000 - 94,000
6.8	11,500 - 45,000	23,000 - 90,000	34,000 - 135,000
10.	17,000 - 67,000	33,000 - 135,000	50,000 - 200,000
15.	25,000 - 100,000	50,000 - 200,000	75,000 - 300,000
22.	37,000 - 145,000	75,000 - 290,000	110,000 - 440,000

UHF THERMOCOUPLES

Ballantine Part No.	Milli-amperes Rating	Approx. Resistance of Couple Circuit (ohms)	Approx. Resistance of Heater Circuit (ohms)
2951	5	8	90
2952	10	8	25
2953	15	4	20
2954	25	4	10
2955	50	4	3

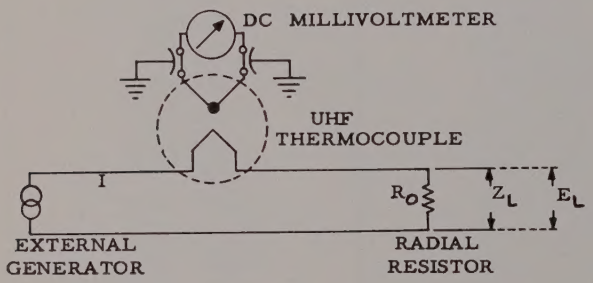
The thermocouples used in Model 440 Micropotentiometers are UHF units manufactured by Best and are available either from Ballantine or from Barker Sales Co., 339 South Broad St., Ridgefield, N. J. as "Best, UHF thermocouple, ... mA."

ADDITIONAL NOTES CONCERNING THE CORRECTIONS FOR LOADING ERRORS WHEN USING MODEL 440 MICROPOTENTIOMETERS

In the past, some confusion has existed in the use of Micropotentiometers having radial resistors of 1 ohm or higher because of the increased importance of loading errors. This note will discuss the problem and describe how loading errors can be computed and their effect compensated.

Loading errors exist when an external load Z_L is small enough to shunt part of the thermocouple current I that normally flows through radial resistor R_O under open-circuit conditions. The effect is to change the voltage E_L across the load from that value determined by the product of I and R_O. Loading errors must be considered not only when a Micropotentiometer is used as a *relative* voltage source, in determining the frequency response of some device, but also when an *absolute* voltage calibration is desired.

The circuit is as follows:



$$E_L = I \frac{R_O Z_L}{R_O + Z_L}$$

Where E_L is the load voltage for a thermocouple current I

$$= E_O \frac{Z_L}{R_O + Z_L}$$

Where E_O is the open-circuit output voltage for a thermocouple current I

$$\text{or } E_O = E_L \left(1 + \frac{R_O}{Z_L}\right)$$

If $R_O << Z_L$, then E_L (the voltage delivered to the load) will equal E_O (the Micropotentiometer open-circuit output voltage) and there will be no loading error.

Notice that the loading effect need not be resistive. At higher frequencies it will also be necessary to measure the reactive part of Z_L to determine if loading errors are present.

In addition, at higher frequencies another effect enters into the loading error. If Z_L is connected to the Micropotentiometer output by a length of transmission line (which is always the case in practice), Z_L will be tranformed to an equivalent Z_L' at the Micropotentiometer output. It is this value Z_L', determined by Z_L, the transmission line characteristics, and the frequency, which must be used in determining the loading error according to the above equation.

Other errors, both at low and high frequencies, are discussed in the Model 440 Instruction Book as well as in "Techniques and Errors in High-Frequency Voltage Calibration," Uiga and White, IRE Trans. on Inst., Vol. 1 - 9, No. 2, Sept. 1960. The latter paper is supplied with each instruction book for the Model 440.

REFERENCES OF VALUE

1. "Application of RF Micropotentiometers for Calibration of Signal Generators to 1000 Mc" by L. F. Behrent in National Bureau of Standards Technical Note No. 37 distributed by U. S. Dept. of Commerce, Office of Technical Services, Washington 25, D. C. Price 50 cents.

2. "Accurate Radio-Frequency Microvoltages" by Myron C. Selby in Communications and Electronics, AIEE 6: 158-164 (May, 1953).

3. "Techniques and Errors in High Frequency Voltage Calibration" by Uiga and White in IRE Transactions on Instruments, Vol. 1-9, No. 2, Sept., 1960. This paper is supplied with each copy of this instruction book. Additional copies will be sent on request at no charge.